aae technologies

004 | 04.2021

High Resolution Seismic Sources: Environmental Considerations and Protection of Marine Wildlife.

Technical Support Document by Michael Calvert

Contents

Introduction

Offshore engineering projects can cover a range of applications including: oil and gas operations, carbon storage, resource mapping/management and the construction of renewable energy projects such as offshore windfarms. Regardless of the projects purpose, geophysical surveys always form an essential part of any project's life cycle and safe execution. Although essential, these surveys must always be designed and carried-out in a way that is as sympathetic as possible to sea life and the marine environment. If not, survey activities particularly seismic surveys, could result in damaging effects on wildlife. Damaging effects that can range from minor behavioural disruptions, to in extreme cases; permanent physical damage.

In this document we review environmental protection standards in the UK, Europe (EU) and the USA and consider how the noise level of seismic sources manufactured by applied acoustics Ltd (aae) compare to these standards. We also consider how aae sources can be employed in a safe manner, limiting the risk of harm to marine wildlife.

Environmental Protection Standards

The UK, EU and USA each have their own governing bodies, responsible for monitoring and regulating anthropogenic noise levels in the marine environment. Although these bodies are separate, they are largely influenced by one another and follow similar protocols (Tasker, 2017).

In the UK/EU region legislation pertaining to seismic surveys stems from guidelines laid-down by the Marine Strategy Framework Directive (MSFD), Descriptor 11 - Marine Noise (Tasker, 2010). This document essentially set-out a requirement for all apoptogenic sound sources within the frequency range of 10Hz to 10kHz and exceeding a sound exposure level (SEL) of 183dB re1μPa^2s or a sound pressure level (SPL_{peak}) of 224dB re 1μPa, to be recorded and entered into a 'noise registry'. The objective being to ensure all loud anthropogenic noises are monitored and that appropriate methods are employed to minimise the risk of injury and disturbance to marine mammals and other wildlife.

Following publication of the 'descriptor 11' report the UK's Joint Nature Conservation Committee (JNCC) published guidelines for geophysical surveys conducted in UK waters (JNCC, Joint Nature Conservation Committee, 2020). Officially, these guidelines only relate to seismic surveys conducted using 'airguns' sources, which produce very loud (>224dB re 1μPa), low frequency (~10-200Hz) sound, that can propagate long distances. They are not considered applicable to sub bottom profiles (SBPs), such as: Pingers, Boomers and Sparkers, as these sources produce lower volume, higher frequency sound (~1 - 7 kHz) which is known to attenuate rapidly.

But does this mean that geophysical survey planners have no need for concern when considering potential impact on marine mammals?

Considerations and Legislation

With the exception of some whale species, marine mammals typically have functional hearing ranges between 5Hz to 200kHz (Landrø, 2010), although they are capable of hearing sound at lower frequencies if loud enough. This puts their hearing in a range that is susceptible to sound frequencies commonly produced by SBPs and could be damaged by over exposure at very close range.

It is worth bearing in mind that the JNCC states that "an operator is expected to make every possible effort to design a survey that minimises the sound generated and the likely impacts to marine mammals." (JNCC, Joint Nature Conservation Committee, 2020) and failure in this regard, leading to injury of a protected species; could constitute a criminal offence.

Furthermore, if working in the USA the "National Marine Fisheries Service (NMFS) currently considers sound levels above 160 dB re 1 μPa (RMS) to constitute Level B harassment under the Marine Mammal Protection Act. Sounds above 180 dB re 1 μPa (RMS) are considered Level A harassment. Thus, BOEM recommends that, where practicable, sound should be kept below these levels. Note that NMFS requires marine mammal monitoring plans for sound levels above these thresholds." (BOAM, 2020).

With these points in mind, it is obviously necessary for users to have a clear understanding of the sound levels generated by aae's seismic sources, so proper mitigation methods can be planned and put in place.

Hazardous Sound Exposure Levels for Marine Mammals

In studies and literature referring to underwater acoustic sound levels, there are two metrics commonly used to describe sound levels; the first of these being Sound Pressure Level (SPL_{peak}). SPL_{peak} gives a measure of the instantaneous sound pressure over a specified time (impulsive sound). In the case of our seismic sources, this is the pressure difference between zero and maximum pulse output.

Sound Pressure Level (SPL_{peak}) =
$20 \log_{10}(P_{peak}/P_{ref})$ [dB re 1μPa]

The second important metric, is Sound Exposure Level (SEL). This differs from the SPL as it takes into account both the impulsive level of sound and the duration of exposure (T = cumulative pulse length over 1 second).

Sound Exposure Level (SEL) =
$SPL_{rms}\ 10\log_{10}(T)$ [dB re 1μPa²s]

Depending on the order and species of marine mammal in question, i.e. cetaceans (whales/dolphins) or pinnipeds (seals); there are a range of sound exposure levels that can result in damage to hearing. Table 1 summarises sound levels which have been shown to result in temporary threshold shifts (TTS) or permanent threshold shifts (PTS) to marine mammal hearing (Southall, 2019).

Range of Exposure	Units	Effect
218 - 232	dB re 1μPa (SPLpeak)	PTS onset in pinnipeds
212 - 226	dB re 1μPa (SPLpeak)	TTS onset in pinnipeds
202 - 230	dB re 1μPa (SPLpeak)	PTS onset in cetaceans
196 - 224	dB re 1μPa (SPLpeak)	TTS onset in cetaceans
185 - 203	dB re 1μPa² S (SEL)	PTS onset in pinnipeds
170 - 188	dB re 1μPa² S (SEL)	TTS onset in pinnipeds
155 - 185	dB re 1μPa² S (SEL)	PTS onset in cetaceans
140 - 170	dB re 1μPa² S (SEL)	TTS onset in cetaceans

Table 1: Values of TTS and PTS in marine mammals, taken from (Southall, 2019).

Hearing ranges of fish and mammals

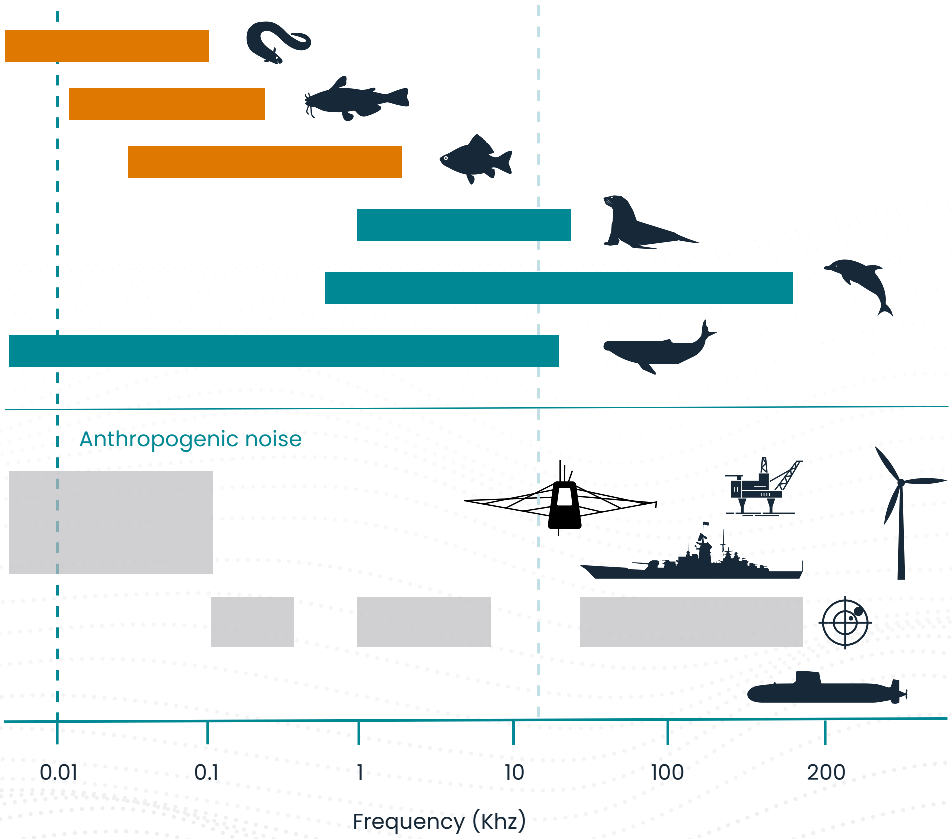

Figure 1: Hearing ranges for fish and mammals (Slabbekoorn, 2010)

aae Boomer (AA301/S-Boom/Dura-Spark 400 Sound Level Estimate

To obtain accurate measurements of sound exposure levels at a given point, readings should be taken in-situ; together with any ambient noise. This is because additional natural and anthropogenic noise sources, i.e. surface waves, weather and distant shipping can contribute both constructively and destructively to the overall noise level. It is however possible to approximate noise levels using readings obtained under controlled conditions.

In this section we set-out **Sound Pressure Levels (SPL_{peak})** measured at 1m from the source for **applied acoustics AA301 Boomer, S-Boom** and **Dura-Spark 400** source systems. We then use these values to estimate **Sound Exposure Levels (SEL)** for each source type, at power settings typically used in 'high resolution geophysical' (HRG) surveys.

Source	Power (Joules)	Pulse length (µs)	Pulses per sec	SPL_{peak} [dB re 1µPa]	SEL [db re 1µPa^{2}s]
AA301 Boomer	300	230	3	209.8	175.2
S-Boom	1000	300	2	220.0	184.7
Dura-Spark 400	800	520	2	222.1	189.3

Table 2: Typical operating settings and SPL_{peak}/SEL levels for HRG survey

If we compare SPL_{peak} and SEL values from Table 2 with exposure ranges in Table 1, we can see that both TTS and PTS exposure thresholds are exceeded at very close ranges (<1m) and there is indeed a danger of causing harm to both cetaceans and pinnipeds.

But how does this change with distance?

To approximate acoustic energy loss, we use the following calculation:

$$\text{Transmission Loss (TL)} = 20 * \log_{10}(r) + \propto * \frac{r}{1000} \text{ (dB)}$$

Where: $\propto = 0.036f^{1.5}$ (dB/km)

(r = range (m), f = frequency (kHz)

Figure 2: Transmission Loss calculation (Richardson, 2013)

Figure 3 and Figure 4 below show SPL_{peak} and SEL acoustic energy attenuation for our three seismic sources in sea water based on the equation in Figure 2 (for Boomer sources, we consider a transmission frequency of 3kHz and for the Dura-Spark: 2kHz). If we apply the same principles to the prolonged sound exposure levels (SEL), we can see that:

- At distances >100m SEL <155 dB re 1μPa² S for all sources (<PTS for all marine mammals).
- At distances >300m SEL <140 dB re 1μPa² S for all sources (<TTS for all marine mammals).

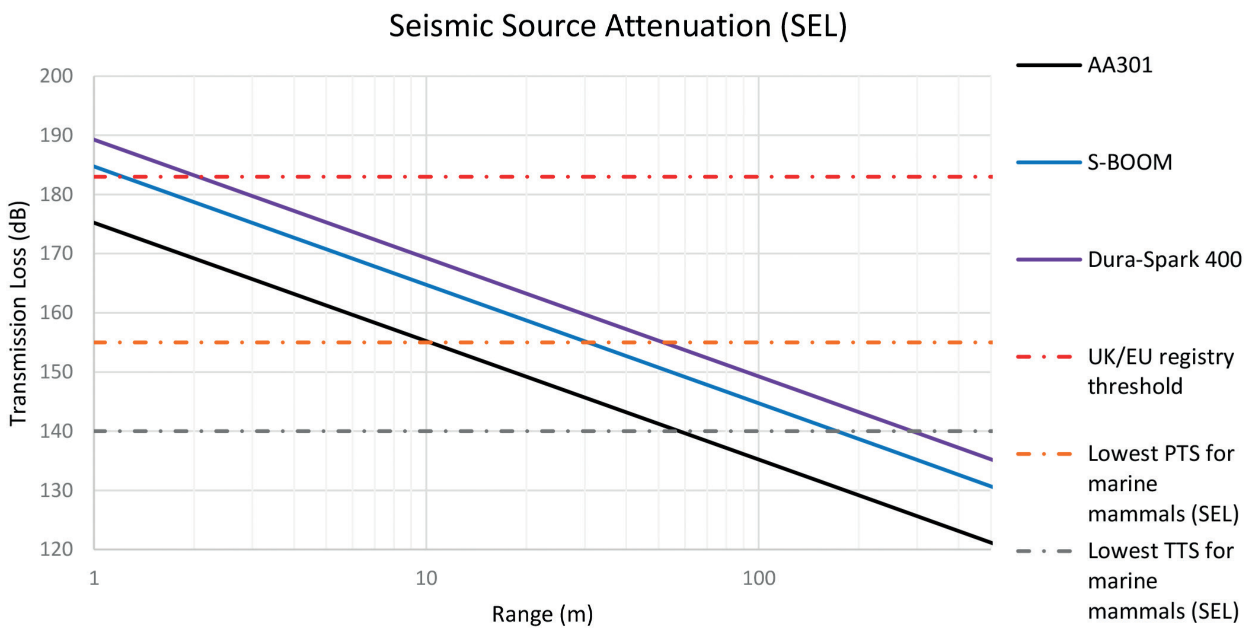

Figure 3: Sound Exposure Level (SEL) attenuation based on equation Figure 2

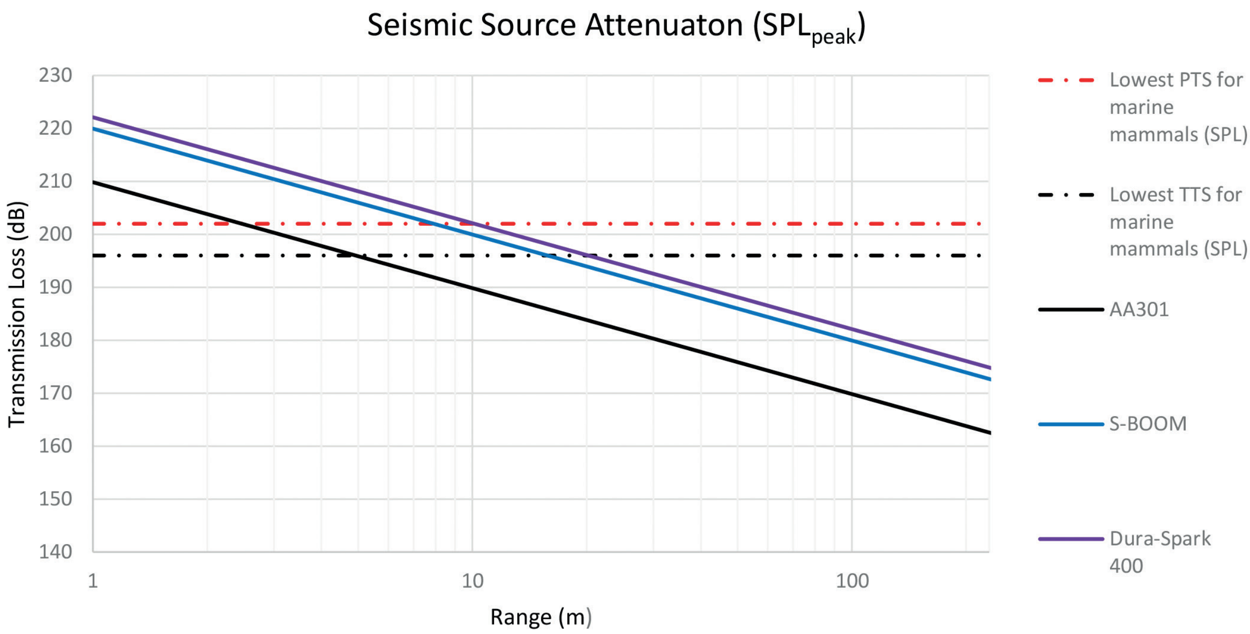

Figure 4: Sound Pressure Level (SPL$_{peak}$) attenuation based on equation Figure 2

Mitigation Strategies

Armed with the information in section 6, it is possible for geophysical survey planners to devise working practices that protect marine mammals from harmful noise exposure. Typical mitigation strategies that could be employed include but are not limited to the following:

Exclusion Zone

An **exclusion zone** is a fixed radius around a seismic source, within which the presence of marine mammals are closely monitored. If any protected species are detected within the exclusion zones, firing of seismic sources must be halted. The standard radius of an exclusion zone during seismic 'Air Gun' surveys is 500m from the seismic source OR centre of source array (if more than one source is being used). This same method can be employed during HRG surveys which use a Boomer or Sparker and it may be possible to reduce this size of the exclusion zone, depending on the power levels in used.

A properly monitored exclusion zone can be an effective mitigation strategy, however there is still the possibility that marine mammals could be within the zone, unobserved, below the water. It is therefore common to employ **soft start** measures to allow for this.

Soft Starts

The aim of a soft start is to reduce sound exposure to any unobserved marine mammals or wildlife in close proximity of the seismic source and can be achieved in one of two ways:

- **Ramp-up:** rather than firing the seismic source at full survey power, firing starts at a lower level and is steadily ramped up over a period of time. This gives warning to any marine life in the area and provides an opportunity for them to move off to a safe/comfortable distance.
- **Limiting Exposure Level (SEL):** An alternative soft start method is to limit sound exposure levels at the start of operations. When this methodology is employed source power levels remain constant, but the time between each shot is varied. For example, stating off with a large time period between each shot (4s) and gradually building up to the desired shot interval (0.5s). In this way, sound exposure level (SEL) is reduced avoiding PTS and allowing marine life an opportunity to move to a safe distance.

Passive Acoustic Monitoring (PAMS)
For operations at night-time or during poor visibility it is often a requirement for PAM systems to be employed. PAM systems utilise underwater hydrophones to listen for distinctive calls made by Cetaceans. Some modern systems are even able to classify species and position the location of any vocalisations detected.

Time/Area Closures
In cases where the above measures are not deemed sufficient or habitats are particularly sensitive, government bodies can and do holt survey operations completely. This is often the case at specific times of the year, when marine wildlife are likely to be breeding, migrating or during important seasonal feeding windows.

Summary

At very close ranges, sound pressure levels (SPL_{peak}) generated by applied acoustics: AA301 Boomer, S-Boom and Dura-Spark 400 source systems, are in excess of levels shown to result in permanent threshold shifts (PTT) in marine mammal hearing (Southall, 2019). Using the calculation given in Figure 2, and typical source operating settings given in Table 2 we estimate that:

- at distances greater than **25m**, sound pressure levels (SPL_{peak}) for all example source types are within PTS limits for all marine mammal species (SPL_{peak} < 196 dB re 1µPa).

Therefore, at distances **>25m**, infrequent exposure should not cause lasting harm to marine mammals.

- at distances greater than **100m**, sound exposure levels (SEL) for all example source types are within TTS limits for all marine mammal species (SEL <155 dB re 1µPa^2 S)
- at distances greater than **300m**, sound exposure levels (SEL) for all example source types are within TTS limits for all marine mammal species (SEL <140 dB re 1µPa^2 S)

Therefore, at distances **>300m**, sound exposure levels are within safe limits, as indicated by Southhall, 2019.

References

A noisy spring: the impact of globally rising underwater sound levels on fish [Journal] / auth. Slabbekoorn H. Niels Bouton, Ilse van Opzeeland, Aukje Coers, Carel ten Cate, Arthur N. Popper,. - [s.l.] : Trends in Ecology & Evolution, 2010. - Issue 7, : Vols. Volume 25,.

Guidelines for Providing Geophysical, Geotechnical, and Geohazard Information [Online] / auth. BOEM. - BOEM, UNITED STATES DEPARTMENT OF THE INTERIOR, Bureau of Ocean Energy Management Office of Renewable Energy Programs, September 2020. - https://www.boem.gov/sites/default/files/renewable-energy-program/G_G_Guidelines_Providing_Geophysical_Geotechnical_Geohazard_Information_Pursuant_to_30_CFR_Part_585.pdf.

JNCC guidelines for minimising the risk of injury [Online] / auth. JNCC, Joint Nature Conservation Committee // jncc.gov.uk. - September 2020. - http://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/jncc-guidelines-seismicsurvey-aug2017-web.pdf.

Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects [Journal] / auth. Southall Brandon L., James J. Finneran, Colleen Reichmuth, Paul E. Nachtigall, Darlene R. Ketten, Ann E. Bowles, William T. Ellison,Douglas P. Nowacek,and Peter L. Tyack. - [s.l.] : Aquatic Mammals, 2019. - 2 : Vol. 45.

Marine Mammals and Noise. [Journal] / auth. Richardson W.J. & Jr, Greene, & Malme, C.I. & Thomson, D.H. & Moore, S.E. & Wiirsig, B. - Marine Mammals and Noise. : [s.n.], 2013.

Marine Seismic Sources Part V: The Hearing Of Marine Mammals [Online] / auth. Landrø M and Amundsen, L // GEOExPro. - 2010. - November 2020. - https://www.geoexpro.com/articles/2010/06/marine-seismic-sources-part-v-the-hearing-of-marine-mammals#:~:text=Marine%20mammals%20have%20a%20mammalian,5%20Hz%20to%20200%20kHz.

MARINE STRATEGY FRAMEWORK DIRECTIVE Task Group 11 Report Underwater noise and other forms of energy [Report] / auth. Tasker M.L. Amundin, M. Andre, M. Hawkins, A. Lang, W. Merck, T. Scholik-Schlomer, Teilmann, A. J. Thomsen, F. Werner, S. & Zakharia, M.. - Luxembourg : Office for Official Publications of the European Communities, 2010.

MSFD Consultation Directive 11, Presentation. TG Noise [Online] / auth. Tasker M. Dekeling, R // SlidePlayer. - 2017. - https://slideplayer.com/slide/16221818/.